REMARKS

The Examiner's continued attention to the present application is noted with appreciation.

The Examiner rejected claims 1-28, 32, 33, and 35-42 under 35 U.S.C. 102(b) as being anticipated by Littau et al (6,429,930). The Examiner also rejected claims 29-31 and 34 under 35 U.S.C. 103(a) as being unpatentable over Littau, et al., and rejected claims 43-77 under 35 U.S.C. 103(a) as being unpatentable over Littau et al. in view of Kroko. Such rejections are respectfully traversed.

The present application properly claims priority to, and incorporates by reference, U.S. Provisional Patent Application Serial No. 60/462,353, "Determination of Center of Focus in Lithographic Applications", filed on April 10, 2003. A copy of the provisional application is submitted herewith for the convenience of Support for the pending claims can be found throughout the specification of the provisional. For example, claim 1 clearly finds support on page 6, line 28 to page 7, line18 and on page 8, line 26 to page 9, line 6.

Littau et al. was first published on August 6, 2002, which is less than one year before the effective filing date of the present application (April 10, 2003). Thus it may not properly be cited as prior art under 35 U.S.C. 102(b). Because Littau et al. is commonly owned and has exactly the same inventors as the present application, it is not "to another". Thus it may not properly be cited as prior art under 35 U.S.C. 102(a) or (e). Applicant therefore respectfully submits that Littau et al. may not be cited as prior art against the present application.

Applicant therefore respectfully requests the issuance of a Notice of Allowance before the statutory date of June 22, 2006. If any issues remain the Examiner is cordially invited to telephone the undersigned agent for Applicant at the telephone number listed below.

Also being filed herewith is a Petition for Extension of Time to April 21, 2006, with the appropriate fee. Authorization is given to charge payment of any additional fees required, or credit any overpayment, to Deposit Acct. 13-4213. A duplicate of the Petition paper is enclosed for accounting purposes.

Respectfully submitted,

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PROVISIONAL PATENT APPLICATION

DETERMINATION OF CENTER OF FOCUS IN LITHOGRAPHIC APPLICATIONS

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RELATION TO OTHER APPLICATIONS

This application is related to PCT/US02/32394, entitled *Determination of Center of Focus by Cross-Section Analysis*, filed October 10, 2002, and to U.S. Patent No. 6,429,930, entitled *Determination Of Center Of Focus By Diffraction Signature Analysis*, issued on August 6, 2002, and the specifications thereof are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention (Technical Field):

The present invention relates to methods for determination of parameters in lithography applications by diffraction signature analysis, including determination of center of focus in lithography applications, such as for photoresist lithographic wafer processing.

Background Art:

Note that the following discussion refers to a number of publications by author(s) and year of publication, and that due to recent publication dates certain publications are not to be considered as prior art vis-a-vis the present invention. Discussion of such publications herein is given for more complete background and is not to be construed as an admission that such publications are prior art for patentability determination purposes.

Lithography has a variety of useful applications in the semiconductor, optics and related industries. Lithography is used to manufacture semiconductor devices, such as integrated circuits created on wafers, as well as flat-panel displays, disk heads and the like. In one application, lithography is used to transmit a pattern on a mask or reticle to a resist layer on a substrate through spatially modulated light. The resist layer is then developed and the exposed pattern is either etched away (positive resist) or remains (negative resist) to form a three dimensional image pattern in the resist layer. However, other forms of lithography are employed in addition to photoresist litholography.

In one form of lithography, particularly used in the semiconductor industry, a wafer stepper is employed, which typically includes a reduction lens and illuminator, an excimer laser light source, a wafer stage, a reticle stage, wafer cassettes and an operator workstation. Modern stepper devices employ both positive and negative resist methods, and utilize either the original step-and-repeat format or a step-and-scan format, or both.

Exposure and focus determine the quality of the image pattern that is developed, such as in the resist layer utilizing photoresist lithography. Exposure determines the average energy of the image per unit area and is set by the illumination time and intensity. Focus determines the decrease in modulation relative to the in-focus image. Focus is set by the position of the surface of the resist layer relative to the focal plane of the imaging system.

Local variations of exposure and focus can be caused by variations in the resist layer thickness, substrate topography, as well as stepper focus drift. Because of possible variations in exposure and focus, image patterns generated through lithography require monitoring to determine if the patterns are within an acceptable tolerance range. Focus and exposure controls are particularly important where the lithographic process is being used to generate sub-micron lines.

A variety of methods and devices have been used to determine focus of stepper and similar lithography devices. Scanning electron microscopes (SEM) and similar devices are employed. However, while SEM metrology can resolve features on the order of 0.1 microns, the process is costly, requires a high vacuum chamber, is relatively slow in operation and is difficult to automate. Optical microscopes can be employed, but do not have the required resolving power for sub-micron structures. Other methods include the development of specialized targets and test masks, such as are disclosed in U.S. Patent Nos. 5,712,707, 5,953,128, and 6,088,113. Overlay error methods are also known, as disclosed in U.S. Patent No. 5,952,132. However, these methods, while increasing resolution because of the nature of the targets, still require use of SEM, optical microscopes or similar direct measurement devices.

A variety of scatterometer and related devices and measurements have been used for characterizing the microstructure of microelectronic and optoelectronic semiconductor materials, computer hard disks, optical disks, finely polished optical components, and other materials having lateral dimensions in the range of tens of microns to less than one-tenth micron. For example, the CDS200 Scatterometer, made and sold by Accent Optical Technologies, Inc. is a fully automated nondestructive critical dimension (CD) measurement and cross-section profile analysis system, partially disclosed in U.S. Patent No. 5,703,692. This device can repeatably resolve critical dimensions of less than 1 nm while simultaneously determining the cross-

sectional profile and performing a layer thickness assessment. This device monitors the intensity of a single diffraction order as a function of the angle of incidence of the illuminating light beam. The intensity variation of the 0^{th} or specular order as well as higher diffraction orders from the sample can be monitored in this manner, and this provides information that is useful for determining the properties of the sample target which is illuminated. Because the process used to fabricate the sample target determines the properties of a sample target, the information is also useful as an indirect monitor of the process. This methodology is described in the literature of semiconductor processing. A number of methods and devices for scatterometer analysis are taught, including those set forth in U.S. Patent Nos. 4,710,642, 5,164,790, 5,241,369, 5,703,692, 5,867,276, 5,889,593, 5,912,741, and 6,100,985.

Scatterometers and related devices can employ a variety of different methods of operation. In one method, a single, known wave-length source is used, and the incident angle Θ is varied over a determined continuous range. In another method, a number of laser beam sources are employed, optionally each at a different incident angle Θ. In yet another method, an incident broad spectral light source is used, with the incident light illuminated from some range of wavelengths and the incident angle Θ optionally held constant. Variable phase light components are also known, utilizing optics and filters to produce a range of incident phases, with a detector for detecting the resulting diffracted phase. It is also possible to employ variable polarization state light components, utilizing optics and filters to vary the light polarization from the S to P components. It is also possible to adjust the incident angle over a range Φ, such that the light or other radiation source rotates about the target area, or alternatively the target is rotated relative to the light or other radiation source. Utilizing any of these various devices, and combinations or permutations thereof, it is possible and known to obtain a diffraction signature for a sample target.

Besides scatterometer devices, there are other devices and methods

capable of determining the diffraction signatures at the 0^{th} order or higher diffraction orders using a light-based source that can be reflected off of or transmitted through a diffraction grating, with the light captured by a detector. These other devices and methods include ellipsometers and reflectometers, in addition to scatterometers. It is further known that non-light-based diffraction signatures may be obtained, using other radiation sources as, for example, X-rays.

A variety of sample targets are known in the art. A simple and commonly used target is a diffraction grating, essentially a series of periodic lines, typically with a width to space ratio of between about 1:1 and 1:3, though other ratios are known. A typical diffraction grating, at for example a 1:3 ratio, would have a 100 nm line width and a 300 nm space, for a total pitch (width plus space) of 400 nm. The width and pitch is a function of the resolution of the lithographic process, and thus as lithographic processes permit smaller widths and pitches, the width and pitch may similarly be reduced. Diffraction techniques can be employed with any feasible width and pitch, including those substantially smaller than those now typically employed.

Diffraction gratings are typically dispersed, in a known pattern, within dies on a wafer. It is known in the art to employ multiple dies (or exposure fields) on a single wafer. Each diffraction pattern may be made by lithographic means to be at a different focus, such as by employing a different focus setting or a different exposure setting or dose. It is also known that center of focus may be determined using scatterometry and diffraction gratings by comparing diffraction signatures from a variety of different focus diffraction gratings to a theoretical model library of diffraction grating signatures yielding information regarding CD. The actual diffraction measures are compared to the model, from which CD values are derived. The CD value thus obtained is plotted against focus and the results fit to a parabolic curve.

U.S. Patent No. 6,429,930, by the same inventors as this application, teaches a method of measuring parameters relating to a lithography device

utilizing the steps of providing a substrate comprising a plurality of diffraction gratings formed on the substrate by lithographic process utilizing the lithography device, the diffraction gratings comprising a plurality of spaced elements; measuring a diffraction signature for at least three of the plurality of diffraction gratings by means of a radiation source-based tool; and determining the differences between the diffraction signatures to determine a desired parameter of said lithography device. In this method, the substrate can include a wafer. The method can further include forming the plurality of diffraction gratings utilizing the lithography device at different known focus settings, and determining the two adjacent focus setting diffraction gratings wherein the difference between the diffraction signatures is less than the difference of the diffraction signatures between other adjacent focus setting diffraction gratings, whereby the parameter is the center of focus of the lithography device.

DESCRIPTION OF THE PREFERRED EMBODIMENTS (BEST MODES FOR CARRYING OUT THE INVENTION)

Determination of the center of focus for a fixed dose during the photoresist development step in wafer processing is critical. Furthermore, dose variations can compound the difficulty in determining this center. The lenses that are used in steppers have a very limited depth of focus, so utmost precision is necessary. Lenses that are in focus will yield sharper printed photoresist images, and lack of focus will result in misdeveloped photoresist features. Being at the center of focus improves process repeatability. A method of determining center of focus is disclosed in this application which utilizes variability analysis; in brief, center of focus is determined by diffraction grating field uniformity. The invention further includes manufacturing process monitoring based on diffraction signature uniformity.

In one technique of this invention, the center of focus for a given dose is determined by analyzing the variability in diffraction signatures or modeled diffraction grating areas or parameters via scatterometry for a series of

gratings (or points within a large single grating) as a function of focus. The technique may be described in more detail as follows. First, a series of fields through focus are printed using a wafer stepper at a fixed dose. Within each field there are a series of diffraction gratings distributed around the field. The field may also consist of one large grating where measurements are made at several points within the large grating, or a combination of the two where there are several large gratings in the field where each large grating is sampled at various points within the grating. The diffraction gratings consist of repeating/periodic structures capable of diffracting radiation. The gratings may either be 2-D (lines and spaces) or 3-D (holes, posts, or more complex) structures. Using a radiation source-based tool capable of scatterometric measurements, the gratings within each field are measured. Using statistical methods, the uniformity of the gratings within the field is calculated, using either the differences in the diffraction signatures themselves or else a specified grating or diffraction structure parameter (such as thickness, CD, or sidewall), or product of two or more specified grating or diffraction structure parameters, preferably by reference to a theoretical model. The theoretical model, used to determine an area as a parameter or to determine individual parameters, may use a simple shape like a rectangle or more complex shapes such as a trapezoid, trapezoid with rounded edges, gaussian or sigmoidal profile, or other custom profiles designated by the user. The theoretical model may also take into account underlying films and patterns. The theoretically-generated traces (with known parameters) are matched to the experimental data to obtain the theoretically-predicted process parameters. Using these process parameters, the area of the grating can also be calculated.

Grating or diffraction structure parameters that may be utilized in a theoretical library include any parameter that may be modeled, including factors such as:

- Critical dimensions (CDs) at the bottom and/or top of the structure

- Height or thickness, such as height or thickness of a line, post or other structure
- Total height of the region defined by a diffraction signature
- Shape of a structure, such as rectangular, trapezoidal, triangular, round or other geometric shapes
- Radius of curvatures at the bottom and/or top of a structure or region
- Period of a grating
- Line or other structure width
- Materials parameters of the structure, including parameters of various layers thereof
- Materials parameters of the substrate on which a structure is posited, such as film thickness and index of refraction of films underneath the structure
- Various weighted or average values, such as CD at a specified location, values weighted by relative contributions of the structure and substrates, or the like

In the practice of this invention, a product of at least two grating or diffraction structure parameters may be employed. The resulting product need not be a geometrically definable shape. In one embodiment, the cross-section includes CD and at least one additional diffraction structure parameter. As used herein, a *product* of at least two grating or diffraction structure parameters is any mathematical operation or manipulation of the at least two parameters, including but not limited to a mathematical operation including multiplication, and optionally at least one second mathematical operation.

A selected uniformity metric (such as standard deviation) is then plotted as a function of focus. The uniformity metric will improve in uniformity from one focus step to the next as the center of focus is approached. Under theoretically ideal conditions, the center of focus is the point at which the

variability in the uniformity of the selected uniformity metric is at a *minima*, which is to say the point at which the uniformity is maximized. In another expression of this method, a parabolic curve can be used to fit the uniformity response to focus, and the center of focus will be at a point where the slope of the parabolic curve is zero. Various other statistical techniques can be used to calculate the center of focus from the uniformity response to focus.

This technique can also be used to monitor focus and/or dose and/or layer thickness drifts in a production setting. Place a variety of gratings in the field, and monitor the variation in diffraction signatures, the variation in a specified grating or diffraction structure individual parameter (such as CD, sidewall, or thickness), or alternatively the variation in a product of two or more grating or diffraction structure individual parameters. Changes in variation indicate a process shift that should be investigated. In addition, as a general process metrology metric, measuring the gratings across an entire wafer and calculating the difference in diffraction signatures can also be used as a model-less approach to wafer uniformity. Low variations in diffraction signatures indicate good process uniformity, while high variations in diffraction signatures indicate poor process uniformity. This applies to many process steps and wafer types, such as the litho, etch and metals steps in semiconductor manufacturing.

For this technique, it may be necessary to have various filters and related mathematical models to remove outliers that may adversely affect the focus analysis.

This technique is applicable to metrology tools that have a radiation-based source that can be reflected off of or transmitted through a diffraction grating, and the radiation captured by a detector. Tools capable of doing these techniques include angle resolved and wavelength-resolved scatterometers, ellipsometers, and reflectometers. Additional tools include any tool that can create a response as a function of a tool parameter or combination of tool parameters that result in a diffraction signature. Candidates for diffraction

gratings suitable for these techniques include photoresist gratings, etched film stack gratings and metal gratings.

The invention thus further includes a method of process control for center of focus in a lithography device, wherein the focus setting of the lithography device is adjusted to the center of focus as determined by the methods disclosed herein. Adjusting the focus setting of the lithography device can include using a computer-based control system. Adjust the focus setting can further include an autofocus control system, wherein at least one input to the autofocus control system includes a parameter relating to the variability in the selected uniformity metric.

Although the invention has been described in detail with particular reference to these preferred embodiments, other embodiments can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art and it is intended to cover all such modifications and equivalents. The entire disclosures of all references, applications, patents, and publications cited above, and of the corresponding application(s), are hereby incorporated by reference.

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